1966

A Twelve Month Study of the Gross and Histologic Changes Occurring in the Jaws of Young Macaca Rhesus Monkeys as a Result of Experimental Surgery

Jerome E. Schoen
Loyola University Chicago

A TWELVE MONTH STUDY OF THE GROSS AND HISTOLOGIC CHANGES OCCURRING IN THE JAWS OF YOUNG MACACA RHESUS MONKEYS AS A RESULT OF EXPERIMENTAL SURGERY

by

Jerome E. Schoen

A Thesis Submitted to the Faculty of the Graduate School of Loyola University in Partial Fulfillment of the Requirements for the Degree of Master of Science

June

1966

ACKNOWLEDGEMENTS

I wish to extend my deep gratitude to Dr. Nicholas C. Choukas whose teaching and guidance have helped me during the past two years of my education and whose example has inspired me to continue this education.

To Dr. Harry Sicher whose teachings and writings have been an invaluable adjunct to my education.

To Dr. Patrick Teto for his guidance during this investigation.

To Dr. John O'Malley and Dr. Nicholas Brescia who generously consented to be members of my advisory board.

To Dr. Robert Pollock and Mr. John Blickenstaff who helped with the photographic work used in this research project.

Dedicated to

My Family

for the many sacrifices both my Wife and

Parents have made to make

my education possible.

LIFE

Jerome E. Schoen was born in Evanston, Illinois, December 15, 1937.

He attended Loyola Academy from September 1951 to June 1955. In September 1955 he entered Loyola University for one semester and then transferred to Xavier University, Cincinnati, Ohio. He entered the Chicago College of Dental Surgery, Loyola University in September 1960 and graduated in 1964. In September of that year he started a two year graduate program leading to a Master of Science Degree in Oral Biology. In November 1965 he received an appointment as a resident in oral surgery at Charity Hospital, New Orleans, Louisiana.

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INTRODUCTION

The growth of the mandible following injury has been the subject of many studies. It is well known that the condyle is the most important growth center of the mandible in primates. The literature concerning this topic is extensive.

In some of these studies monkeys have been used because of the close anatomic relation of their temporomandibular joint to that of man.

The studies have included many different experimental procedures. Usually the results of these studies are controversial. In particular, many surgically induced injuries to the condyle of the monkey have been reported after relatively short periods of post surgical survival time.

The purpose of this experiment is to study after one year the gross and histologic changes in the jaws of young Macaca rhesus monkeys subjected to:

A. Intracapsular subcondylar fracture and displacement of the condyle.

B. Condylectomy.

C. Subcondylar fracture of the mandible with reduction and transosseous wire fixation.

The information gained in this experiment may lead us more fully to understand the complications of growth and development of the injured mandible in humans, particularly children.

LITERATURE REVIEW

Stuteville and Jarabak in 1952, resected the condyle unilaterally in a monkey. The condyle was reduced and fixed by means of a vitallium plate. Six months after surgery the animal was sacrificed. The condyle was found to be growing normally. There was good fusion and healing in the fracture site and an overgrowth of bone partially obscuring the vitallium plate. There was no evidence of ankylosis and the articular eminence was normal. No change in incisal or occlusal relation of the mandible was present.

In 1954 Jarabak surgically removed the mandibular condyles in a young monkey. The monkey was sacrificed twelve months after surgery. Jarabak found that after the removal of the mandibular condyle from its fossa, a new fossa had developed on the articular eminence in response to the function of the stump. At the site of resection some bone opposition was present and there was a hinge joint formed. There was an increase in depth of the antigonial notch and the angle of the mandible was more acute. The operated monkey also had a loss of incisal relation caused by the depression of the most posterior molar into the alveolar bone after condylectomy.

In 1957 Sarnat resected the condyle in a group of young Macaca rhesus monkeys. The animals were sacrificed after a period of twenty-five to thirty-five months of postoperative experimental time.

In these animals the mandible was not ankylosed. The animals which sustained bilateral condylectomy had a loss of incisal relation while some of the animals which sustained unilateral condylectomy showed a deviation of the mandible to the effected side. All of Sarnat's monkeys demonstrated a thickened false condyle functioning anterior to the glenoid fossa with one excep-

tion. This was one unilaterally condylectomized animal which showed a mandibular amputation site with no evidence of cartilage being replaced by bone, no articular disc, but only a fibrous tissue joint.

In most of Sarnat's animals the glenoid fossa was shallower and the postglenoid process was shorter than normal. The coronoid process extended above the zygomatic arch while the ramus was shorter with no true sigmoid notch. There was a decrease later in the mandibular angle and the height of the body of the mandible. Also, the antigonial notch was accentuated.

Roentgenographs in these monkeys showed a more radiolucent ramus and a reorientated trabecular pattern.

Huerlin, Gans and Stuteville in 1961 produced condylar fractures in four adult monkeys (Macaca rhesus). Two monkeys sustained bilateral fractures and the other two sustained unilateral fractures. The monkeys were sacrificed twelve months after surgery. After sacrifice the following skeletal changes were seen: The unilaterally operated animals showed facial assymetry while the bilaterally operated animals demonstrated symmetrical deformities.

Skeletal changes occurring in the affected side of the animals with unilateral fractures included an anterior repositioning of the new temporomandibular joint, a decrease in the height of the maxilla and mandible in the molar area, a decrease in the height of the ramus, an increase in the elevation of the coronoid process above the level of the zygomatic arch, a disarrangement of the trabecular pattern in the ramus, a flattening of the articular eminence and a reduction of the depth of the glenoid fossa.

In the bilaterally operated animals the skeletal changes on both sides were a decrease in the facial height, an anterior repositioning of the tempo-

romandibular joint, a decrease in the gonial angle, height of the ramus, height of the alveolar ridge in the maxillary molar region, and a decrease in the height of the glenoid fossa. These animals also demonstrated an elevation of the coronoid process above the level of the zygomatic arch, a disarrangement of the trabecular pattern in the ramus, a flattening of the articular eminence and an anterior loss of incisal relation.

In 1960 Walker produced fracture dislocations of the mandibular condyle in nine Macaca rhesus monkeys. Using a submandibular approach to the area of surgery, he unilaterally or bilaterally fractured the mandibular necks and displaced the condylar fragment in an anterior and medial direction. In three animals which sustained unilateral mandibular surgery the fracture fragments were reduced and fixed with transosseous wires. Intermaxillary fixation was used on one operated animal. Antero-posterior radiographs of the condyles were taken preoperatively, postoperatively and at the time of sacrifice, sixteen to twenty months after surgery.

Walker found a functional, growing, articulating condyle on the operated mandibles. No loss of incisal relation or deviation of the mandible was seen. A higher reattachment of the massetar muscle except in the animal with intermaxillary fixation, and no significant changes in growth of the mandible except for a decrease in the antero-posterior width of the ramus associated with the operated condyles was reported.

In a later study Walker unilaterally fractured the condyles of four young monkeys. Following surgery the jaws of all four animals were immobilized with intermaxillary fixation. The animals were sacrificed twelve months after surgery, and demonstrated a thickened but functioning condyle in an

upright position within the articular area. Microscopic sections of these condyles demonstrated a distinct fibrous covering, zone of cartilage, zone of ossification and bone in the usual anatomic order.

In 1965 Kaczala conducted a study using six Macaca rhesus monkeys. Three monkeys sustained unilateral, and three monkeys sustained bilateral subcondylar fractures of the mandible. No attempt was made to reduce or fix the fracture sites. Two monkeys, one unilateral fracture and one bilateral fracture, were sacrificed two months after surgery, two at four months and two at six months. Kaczala compared the experimental results to two control animals.

Kaczala concluded that all intracapsular subcondylar fractures of the mandible heal if well aligned, even though the fracture fragments were not reduced or fixed.

A medio-lateral widening occurred at the healing site. Endochondral bone formation persisted in all condyles except one. In this animal a pseudoarthrosis occurred at the fracture site. A loss of incisal relation occurred in two animals with bilateral subcondylar fractures.

In 1965 Guccione conducted a study using eight Macaca rhesus monkeys. Mandibular unilateral condylectomies were performed on three monkeys and bilateral condylectomies were performed on three monkeys. A pair of monkeys, one unilaterally operated and one bilateral, was sacrificed at four months, six months, and eight months. The two control animals were sacrificed at six months and eight months. He found that all the animals were able to masticate their normal diet within three days. A loss of incisal relation of 1 mm. was observed in all bilaterally operated animals and a deviation of the mandible was observed in one unilaterally operated animal and one bilaterally operated

animal. All of the amputation sites produced a new condyle-like structure which was functional and contained the histologic structures of a normal condyle. When the mandible of the operated animals were compared to the control animals the measurements did not differ significantly.

In 1965 Zielinski, using three monkeys aged twelve, fifteen, and seventy-two months studied the normal masticatory apparatus of the Macaca mulatta monkey. A gross dissection of the muscles of mastication and temporomandibular joint was performed on two animals and a histologic study of the condylar endochondral growth center was performed on the third monkey. A detailed description of the skull, temporomandibular joint, muscles of mastication and permanent dentition was presented. The masticatory apparatus of the monkey was then compared to that of man.

In 1964 Dingman and Natvig gave a detailed description of the preauricular approach to fractures of the mandibular condyle.

They stated that "an auriculo-temporal incision is carried to the parotideomasseteric and temporal fascial. A flap is made on this level and the tissues are retracted forward. The condyle or the fossa can be palpated beneath the fascia. The fascia is incised horizontally over the zygama, and the incision is carried downward and backward on a line corresponding to the posterior margin of the mandible. Blunt dissection of the deeper structures leads to exposure of the condyle."[1]

1. Natvig, Paul, and Dinghan, Reed O. Surgery of Facial Fractures. Philadelphia: The W.B. Saunders Co., 1964.

MATERIALS AND METHODS

EXPERIMENTAL PLAN

Seven Macaca Rhesus monkeys, five males and two females, were used in this investigation.[1] Estimations made from the weight, palm length, crown rump measurement and dental age indicated that these animals were between eighteen and twenty months of age at the beginning of the experiment.

The animals were housed in stainless steel animal cages and maintained with dry monkey biscuits[2] once a day, plus bananas and oranges injected with .6 ml. of vitamin supplement.[3]

Briefly, the design of the experiment was as follows: The six animals to be operated were divided into three pairs. Intracapsular subcondylar fractures were produced on four monkeys. In one pair of animals, numbered two and four, the fractures were reduced and fixed by interosseous wiring. The fractured condyles of the other pair, numbered one and six, were displaced and without reduction or fixation the site of surgery was closed. Condylectomies were performed on monkeys numbered three and five. One animal in each pair was subjected to unilateral surgery and the other to bilateral surgery. Animal number six was operated two months later than the other five and therefore, was sacrificed after a ten month postoperative experimental period. The other animals, including the one unoperated animal which served as a control, were sacrificed after a twelve month postoperative experimental period.

1. The animals were obtained from Shamrock Farms, Inc., Middletown, New York.
2. Rockland Primate Diet, Teklad Inc., Monmouth, Illinois.
3. Vi-Daylin Drops, Ross Laboratory, Columbus, Ohio.

PRE-EXPERIMENTAL PREPARATION AND ANESTHESIA

In preparation for surgery a squeeze cage was used to remove the animals from their resident cages. The animals were weighed and the dosage of anesthetic to be used was calculated. Anesthesia was obtained by injecting 1 cc of a 5 mg./cc concentration of phenobarbital sodium in a diluent composed of alcohol, 10%, propylene glycol, 20%, and sterile water for each 5 pounds of weight.[1] Using a 25 gauge needle the anesthetic agent was introduced into the Saphenous vein. In some instances it was necessary to supplement the original injection due to the variable reaction of the animals to the anesthetic, and variations in the length of the experimental procedure.

Preoperative records of the weight, hand length and crown rump length were recorded, and the sex of each animal was noted. The hand length was measured from the tip of the third finger to the proximal edge of the hypothenar eminence, and the crown rump length was measured from the base of the tail to the top of the skull. Using an autopolymerizing methyl methacrylate synthetic resin,[2] impressions of the dental arches were taken. These were used later to determine the status of the dentition. Right and left lateral head films and antero-posterior cephalometric roentgenographs were taken.

A cephalostat was used to hold the animal during radiographic procedures. Medical x-ray film in an 8 x 10 cassette with a double intensifying screen was used.[3] A dental x-ray unit set at 115 K.V.P. and 15 ma. was used to expose the film for three-fourths of a second. The target to film distance was thirty-nine inches. The above described determinations of growth and

1. Nembutal Sodium, Abbott Laboratories, North Chicago, Illinois.
2. Ontray Quick-Cure Acrylic, William Getz, Inc.
3. Eastman Kodak Co., Rochester, New York.

recovery were repeated every two months fro a period of one year.

EXPERIMENTAL SURGERY

The monkey was positioned on the animal operating table and the area of surgery was shaved. The monkey's face and neck were scrubbed from the clavicles to the eye and from the ear to the midline of the face. The animal was then covered with sterile drapes exposing only the area of surgery. Sterile technic was observed during the experimental surgery. An"auriculo-temporal incision" as described by Dingman was made with a number 15 Bard-Parker blade. The incision was carried to the depth of the parotideomasseteric fascia. By blunt dissection the capsule of the joint was exposed. An incision was made through the lateral aspect of the capsule and parallel to its fibers.

Six monkeys were subjected to experimental fracture through the neck of the mandible with a 701 tapered fissure bur in a surgically prepared dental handpiece. Warm normal saline was dripped during the cutting process as a coolant and lubricant. In animals numbered one and six the condyles were separated from the mandible and displaced medial to the vertical plane. In animals numbered two and four a hole was drilled with a 701 tapered fissure bur on each side of and approximately 4 mm. from the line of surgical fracture.

The fracture was reduced and then fixed by placing a transosseous wire across the line of fracture. In the third pair of monkeys the condyle was loosened from the capsule and articular disc with a periosteal elevator, detached from the lateral sterygoid muscle and removed. The capsule, parotideomasseteric fascia and subcutaneous tissues were approximated with interrupted No. 000 plain catgut sutures and the skin with interrupted

No. 0000 black silk sutures. Plastic spray bandage was applied over the wound.[1]

Immediately after surgery, 1,200,000 units of sterile benzathine penicillin G (Bicillin) and 600,000 units of sterile procaine penicillin G (Wycillin) were injected intramuscularly (Gluteal Muscle) in a prophylactic capacity.[2] Postoperative right and left lateral head and antero-posterior cephalometric radiographs were taken. The animals were returned to their cages and kept on a soft diet (bananas and water soaked monkey biscuits) for ten days.

SACRIFICE AND FIXATION

After a postoperative period of twelve months the animals were anesthetized as before, the chest was opened, the descending aorta was clamped with a hemostat about five centimeters from its origin and the left ventricle of the heart was incised. A glass canula was pushed through the incision in the left ventricle and into the ascending aorta. A No. 000 black silk suture was tied around the ascending aorta and canula to hold the latter in place. The head, neck and upper limbs of the animal were perfused with 7% sodium citrate in water followed by 10% buffered formalin. Following fixation the animals were decapitated at the clavicular line. Antero-posterior roentgenographs were taken and the heads were hemisected along the saggital plane with a Stryker autopsy saw. Lateral head films were taken of the right and left halves.

HISTOLOGIC PREPARATION

Using a diamond disc in a dental handpiece a block section of the entire

1. Silicote, Arver-Stave Laboratories, Inc., Mt. Prospect, Illinois.
2. Wyeth Laboratories, Philadelphia, Pa.

mandibular joints was removed and suspended in 10% buffered formalin for forty-eight hours. The specimens were washed free of the fixative in running water for the three hours and placed in decalcifying solution (sodium citrate 25%, formic acid 75%). The completion of decalcification was determined by observing radiopacity on intermittent roentgenograms and required a period of from seven to den days.

The specimens were washed in running water for eight hours, and then dehydrated in nine thirty minute alcohol baths, (three 75%, three 95%, and three 100% alcohol baths). Next the specimens were placed in three Xylene baths for ten minutes each. They were placed in liquid paraffin (55°C) in a vacuum oven for one and one-half hours and finally imbedded in a paraffin block.

Sections (peripheral, para-central, central) twelve microns thick, were cut parallel to the medial-lateral axis of the condyles and placed on slides for staining. The sections were stained with hemotoxylin and eosin.

MEASUREMENTS

Animal number three and animal number five presented a loss of incisal relation. The deformities were measured by direct measurement before the two animals were sacrificed. The measurement was made in the midline of the maxilla between the incisal edges of the maxillary and mandibular teeth. After the block sections of the temporomandibular joints were removed from the monkey heads, the soft tissue was dissected away from the mandibles and direct measurements were made on these specimens. The height of the coronoid process was measured from its highest point to the inferior border of the

mandible along a line perpendicular to the mandibular plane. The height of the mandibular body was measured from the highest point just anterior to the first permanent molar to the inferior border of the mandible along a tangent perpendicular to the mandibular plane. The length of the mandible was measured from the anterior point on the mental protuberance to the posterior border of the mandible along a line horizontal to the mandibular plane. The above measurement was made using conceptual projection and was not measured on the curve. The width of the ramus of the mandible was measured from the anterior to the posterior border of the ramus along a line horizontal to the mandibular plane and superimposed over the mandibular foramen.

FINDINGS FOLLOWING SURGERY

All six animals tolerated the anesthesia and surgical procedure successfully and recovered uneventfully. Moderate edema was visible in the area of surgery for approximately seventy-two hours postoperatively. There was no evidence of infection or facial nerve damage in any of the animals. The animals accepted a soft diet, and when they masticated no apparent deviation of the mandible was visible. After ten days the soft diet was replaced with the regular diet, which was also consumed without apparent difficulty. All animals showed a continued increase in crown rump length, hand length, and weight except animal number 2, which showed a 0.5 lb. loss of weight at the first postoperative check but had gained weight again at the four month postoperative check. (Table 3-9)

The occlusal relations remained normal in all animals except numbers 3 and 5. Animal number 3 (right unilateral condylectomy) demonstrated an open incisal relation of 0.5 mm. at the first postoperative check and 0.75 mm. at the second postoperative check at four months. At the time of sacrifice, this animal had a loss of incisal relation of 0.75 mm. in the midline and 1.25 mm. between the left lateral incisors. (Figure 2) Animal number 5 (bilateral condylectomy) also showed an open incisal relation of 0.5 mm. at the first postoperative check and 0.75 mm. from the second postoperative check until sacrifice. (Table 3 to 9) (Figure 1) This animal also had a 1 mm. deviation of the mandible to the right. (Tables 3 to 9) (Figure 1) At the beginning of the experimental period a deciduous dentition was present in all the animals except animal number 4, which had permanent mandibular first molars and animal

number 6, which had both maxillary and mandibular permanent first molars erupting in the oral cavity at the time of surgery. By the fourth month all the monkeys had the permanent first molars present in the oral cavity. (Tables 1 to 9)

POSTMORTEM EXAMINATION

The maxilla, mandible and temporomandibular joint in the control animal and in the unoperated condyles of the unilaterally operated animals were comparable to the normal Macaca rhesus monkeys described by Zielinski in his study in 1965.

In the control animal the ramus width measured at the height of the mandibular canal did not differ more than 0.2 mm. between right and left sides. Measurement of the height of the coronoid process showed a difference of 0.3 mm. between the right and left sides. The length of the mandible when measured showed a difference from right to left sides of 0.2 mm. (Table 2)

In animals numbered 1, 2, 4, and 6 (fractured condyles) the temporomandibular joint showed no signs of ankylosis or loss of normal range of movement when the jaws were opened manually. Palpation and dissection of the joint at sacrifice showed an enlarged capsule on the operated condyles when compared with the control animal and the unoperated contralateral sides. The position of the condyle was in a characteristic relation to the articular eminence of the temporal bone. The fracture sites were wider mediolaterally but showed continuity of bone.

The mandibular ramus was similar in shape and thickness to that of the unoperated side and the control animal. When comparing the width of the ramus

of the unoperated side to the operated side the difference was not more than 0.3 mm. When compared to the control this group did not differ more than 2.2 mm. (Table 2)

There was no observable difference in the coronoid process on the operated side in these animals when compared with the unoperated sides or the control animal. When measured, the height of the coronoid process did not differ more than 0.2 mm. from operated to unoperated sides and 3.3 mm. when compared to the control. (Table 2)

The body of the mandible of these animals did not differ in shape or thickness when compared to the unoperated animal. When comparing the unoperated condyles to the operated condyles in these animals the length of the mandible did not differ more than 0.8 mm. and the height of the mandible did not differ more than 0.2 mm. When compared to the unoperated control animal the length of the mandible did not differ more than 4.2 mm. and the height of the mandible did not differ more than 2.8 mm. (Table 2)

The dentition in these animals showed a normal eruption pattern and no malposition of the teeth. There was no sign of a mandibular deviation in any of the animals that sustained condylar fractures.

HISTOLOGIC FINDINGS ON CONTROLS

Histologic sections of the temporomandibular joints of the unoperated control monkey and the unoperated condyles of the experimental monkeys revealed a diarthrosis between the condyle and the temporal bone with a fibrous disc between these articulating bodies. The articulating eminence of the temporal bone was covered with dense fibrous connective tissue. The articular disc was

composed of tightly packed dense fibrous tissue with numerous fibroblasts scattered throughout. The condyles were covered with a layer of dense fibrous connective tissue. Interposed between this connective tissue and the supporting bone was a hyaline cartilage layer which could be divided into three zones. Blending with the connective tissue the chondrogenic zone was cell rich and consisted of many basophilic stained chondrocytes and little intercellular substances. The middle zone contained large spherical cells which became progressively larger and degenerated in the lower zones. Finally, there was a zone of calcification and bony replacement which consisted of many degenerating chondrocytes and thin immature bony trabeculae. The condyles which had been subjected to experimental fracture were comparable histologically to the condyles in the control animal.

GROSS FINDINGS IN THE CONDYLECTOMIZED ANIMALS

In animal number 5 (Bilateral condylectomy) both right and left temporomandibular joint areas showed evidence of a functional articulation. The joint cavity was enclosed in a fibrous capsule similar to that of the control animal. The position of the new mandibular articular surface on the left side seemed relatively normal but the articular surface was wider than normal antero-posteriorly. The right condyle was normal in size.

When palpated the lateral pole of the right condyle was in a medial position in relation to the temporal bone as compared to the condyle on the left side and that in the control animal. The right zygomatic arch was not as well developed as the left or the zygomatic arches of the control. (Figure 1)

In animal number 5 the right and left rami were similar in size and shape to that of the control. The width of the ramus did not differ from one side to the other more than 0.2 mm. and when compared to the control did not differ more than 0.1 mm. (Table 2)

The shape and size of the coronoid processes were similar to that of the control. The measurement of the height of the coronoid process did not differ from one side to the other more than 0.4 mm. and when compared to the control did not differ more than 3.4 mm. (Table 2)

The mandibular body was similar in shape and size to that of the control. The length of the mandible, when one side was compared to the other, differed not more than 0.2 mm. When compared to the control the length of the mandible differed not more than 1.8 mm. and the height of the mandible differed not more than 0.1 mm. (Table 2)

The eruption pattern and position of the teeth in animal number 5 was normal. However, the mandible deviated from the midline. (Figure 1)

In animal number 3 (right unilateral condylectomy) the right articulation showed a capsule similar to that of the left side. The articular head was short and tipped in an antero-medial direction, and was 2 to 4 mm. smaller medio-laterally than the normal condyle on the left side. The right zygomatic arch appeared thinner than the arch on the left side and the coronoid process extended higher than the zygomatic arch on the right side when compared to the left side. (Figure 4) When the jaws were opened, the right articular head did not slide downward and forward. Only a hinge-like movement was observed.

The shape and thickness of the ramus on the operated side was similar to

that of the unoperated side. The width of the ramus differed from one side to the other by 1.3 mm. The ramus was smaller on the condylectomized side when compared to the normal side. When the operated side was compared to the control it did not differ more than 1.4 mm.

The shape and thickness of the coronoid process on the right side was similar to the coronoid process on the left side and the measurement of the length of the coronoid process did not differ from one side to the other more than 2.6 mm. The length of the right coronoid process when compared to the control did not differ more than 4.3 mm. The shape and thickness of the mandibular body of this animal was similar to the control animal. The length of the mandibular body from the operated to the unoperated side showed a difference of no more than 1.5 mm. and the height of the mandible from one side to the other would show a difference of no more than 2.4 mm. The lnegth of the right side of the mandible when compared to the control showed a difference of no more than 1.6 mm. while the height showed a difference of no more than 0.5 mm.

HISTOLOGIC FINDINGS

CONDYLECTOMIZED ANIMALS

Animal number 5 (bilateral condylectomy) presented a reconstructed though deformed articular surface on both right and left sides of the mandible. The articular surface of the right temporal bone showed evidence of a fibrous covering and seemed to be unaffected by the surgery. The fibrous covering contained fusiform fibroblastic nuclei scattered throughout with tightly packed collagenous fibers lying parallel to the uneven bulbous articular sur-

face of the mandible.

A potential joint cavity was in evidence with intervening dense connective tissue replacing the meniscus. This connective tissue was bound to the articular surface of the mandible. The connective tissue was composed of dense collagenous fibers, some in a basket weave arrangement, others lying parallel to the surface of the articular eminence. At the medial aspect of this connective tissue mass, striated muscle fibers could be seen. It could not be determined whether or not the muscle tissue possessed an attachment to the connective tissue. Between the eminence and condyle toward the medial and lateral periphery of the connective tissue there was evidence of a synonial lining.

A defect ran through the length of the mandibular articulation in an antero-posterior direction. This defect appeared to be made up of dense connective tissue with island-like inclusions of loose connective tissue containing blood vessels. The connective tissue made a syndesmotic-like union between the two masses of bone. These two bony masses were made up mostly of coarse, fibrillar immature bone, and showed evidence of hemopoetic marrow. The medial bony mass was undergoing extensive resorption on its most medial aspect where it is in contact with the connective tissue capsule. In the connective tissue adjacent to the articular surface there appeared to be a fragment of cartilage and bone surrounded by a distinct cell rich zone. However, this could have been an extension of the bony surface of the mandibular eminence. These fragments showed evidence of current and past osteoclastic activity.

The articular eminence of the mandible showed evidence of a cell rich

zone made up of fibroblasts. This zone was slightly varied in thickness. The proliferating cartilage was arranged in territories in an irregular fashion and in varied degrees of thickness. In some areas there was no evidence of regimented cartilage proliferation. Osteoclastic and osteoblastic activity was present in the peripheral areas of the articular eminence. In the ramus the bone marrow showed more osteoblastic than osteoclastic activity demonstrating productive reconstruction.

The mandibular eminence on the left side of animal number 5 showed a similar deformed reconstruction like the right side although the connective tissue between the temporal bone and mandibular articulation seemed to be attached to both and had more blood vessels scattered throughout. The striated muscle shown on the medial aspect of this mandibular eminence is definitely attached to the connective tissue.

The right temporomandibular joint in animal number 3 (right unilateral condylectomy) failed to show condylar reconstruction in the accepted sense. The cavity between the temporal bone and the amputation site on the mandible was filled with dense connective tissue. On the medial and lateral aspects of the joint areas some striated muscle tissue was seen extending between the mandible and the temporal bone. Patent blood vessels were also noted. The connective tissue was attached to the bony surface of the mandible but no hyaline cartilage was present between the connective tissue and the mandibular supporting bone. In the middle of the amputation site, medio-laterally, and close to the bony surface, reversal lines covered by new bone were seen. In the peripheral areas and in the marrow spaces of the ramus osteoblastic activity was in evidence. (Figure 9)

DISCUSSION

ANIMALS WITH FRACTURED CONDYLES

In this investigation, three surgical procedures were used. Two Macaca rhesus monkeys sustained experimental fracture and reduction and fixation of the condyle, two monkeys sustained condylectomy, and two sustained experimental fracture of the mandibular condyle with displacement.

The animals which sustained experimental fractures demonstrated continuity of bone in the line of fracture when their mandibles were examined at the time of sacrifice. However, there was a medio-lateral widening at the site of fracture similar to that described by Kaczala (1965) and Stuteville and Jarabak (1952). This medio-lateral widening was a bony callus and given more time would probably have diminished by continual bone remodeling.

There was no gross deformity of facial symmetry in these animals. The measurements of the mandible showed minimal difference when compared to the control. In 1961 Huerlin, Gans, and Stuteville showed assymetry of the face and discrepancies in the mandible following fracture dislocations. Since they used adult animals in their research, they eliminated growth at the condylar growth center as the cause of the assymetry of the face and said probably that it was due to an anatomic loss of bon continuity, functional adaptation of bone, and muscle imbalance.

In this study loss of incisal relation was not evident in any animal which sustained fractured condyles. Kaczala (1965) reported two animals out of six with fractured condyles showed a loss of incisal relation. One of these animals developed a pseudoarthrosis in the line of fracture, but the

other seemed to have a normally healed condyle.

In 1961 Huerlin, Gans and Stuteville reported a loss of incisal relation in two out of four monkeys. Both of these animals sustained bilateral condylar fracture and displacement. The reason that no loss of incisal relation in animals with experimentally produced fractures occurred in this study was probably due to the suturing of the joint capsule forcing the condyle when in function to return to its original position in a short time in the two animals with displaced condyles. In the other two animals with fractured condyles the bony fragments were fixed with transosseous wires and therefore, held in place.

When the temporomandibular joints were dissected the joint capsules were "larger" in the operated condyles. Kaczala (1965) also found this in his study. This finding is probably a result of the trauma in the temporomandibular joint area caused by the surgery and the movement of the mandible during mastication after surgery.

CONDYLECTOMIZED ANIMALS

In both animal number 3 and 5 a loss of incisal relation was evident two months following surgery. This loss of incisal relation increased after four months and remained stable for a year. This loss of incisal relation was possibly caused by a transfer of the masticatory pressure area from the temporomandibular joint to the most posterior mandibular teeth in these animals. This new pressure point is due to the backward and upward pull of the masseter, temporal, and medial sterygoid.

The increase in the distance of the inter-incisal relationship in the

first four months following surgery was shown both in this study and in Guccione's (1965) study.

Over the twelve month period of the experiment there was no decrease of incisal relation as reported by Huerlin, Gans, and Stuteville (1961). However, an age difference in the animals used in this experiment (18-20 months) and Huerlin's experiment (42-44 months) could have a bearing on this finding. Possibly the teeth can erupt only fast enough to parallel the growth of the jaws in a younger animal. While in the fully grown animal the jaws are fully developed and through attrition the occlusion closes.

Huerlin, Gans, and Stubeville (1961) reported immediate loss of incisal relation in two of their animals while Jarabak (1954) claims the loss of inter-incisal relation is not apparent for three months and is due to a depression into the bone of the most posterior mandibular molars.

This experiment and Guccione's experiment (1965) showed an open incisal relation at two months, but since this was the first careful postoperative check following surgery it is possible that the animals had an open bite immediately following surgery. The inter-incisal articulation did not change from the fourth to the twelfth month and it seems that the second deciduous molars rather than being depressed into the alveolar bone held the occlusal relation while the first permanent molars erupted to the height of this occlusal plane.

In animal number 5 (bilateral condylectomy) there was a 1 mm. deviation of the mandible to the right. Guccione (1965) had a similar finding in one of his animals which had sustained resection of both condyles. Huerlin, Gans and Stuteville (1961) had a similar finding in an animal in which they pro-

duced bilateral fractures of the condyle.

This is probably due to unequal pull of the muscle of mastication on both sides of the mandible with a resultant deviation of the mandible to the stronger side. Inequality of repair is fibrous ankylosis, perhaps.

In animal number 3 and 5 the zygomatic arch on the right side was thinner than that of the left. Huerlin, Gans and Stuteville (1961) and Sarnat(1957) had this finding in a number of their animals. Sarnat says that this is probably due to functional influence of the muscles of mastication. If this experiment had included a study of the muscles on mastication a partially attrophied masseter muscle might possibly have been found on the side of the animal which demonstrated the underdeveloped zygomatic arch.

In animal number 5 reconstruction of both condyles was seen. These condyles were malformed but did not show good function and areas of hyaline cartilage growth. The process of growth in the monkeys was not observed in this study.

In Guccione's (1965) study and in previous studies on young Macaca rhesus monkeys findings in the condylar region after condylectomy for the most part showed the formation of a functional articular process which lacked the normal morthology of a condyle. However, Walker (1960) did report a substantial reformation for the condyle in a unilaterally condylectomized animal similar to that found in animal number 3 in this study. Sarnat in 1953 reported observing a condyle-like structure with no evidence of any cartilage or bony replacement. Instead a layer of dense fibrous connective tissue was found attached to the ramus and articulating with the temporal bone. Animal number 3 in this study showed a similar fibrous connective tissue joint.

SUMMARY AND CONCLUSIONS

Seven Macaca rhesus monkeys were used in this investigation. Intracapsular subcondylar fractures of the mandible were produced in four animals, and mandibular condylectomies in two and the seventh animal was used as a control. Twelve months after surgery the animals were sacrificed. Measurements of the mandible and histologic sections through the temporomandibular joint were prepared.

The following results were obtained:

1. The animals which sustained condylar fractures showed larger temporomandibular joint capsules, good position of the condyles in relation to the temporal bone, continuity of bone, but mediolateral widening of the fracture sites. Eruption and occlusion of the teeth and the measurements of the mandible of the operated animals compared favorably to the measurements of the mandible of the control.
2. The animal which sustained bilateral condylectomy of the mandible showed a loss of incisal relation and deviation of the mandible, an aborted but functional attempt at reconstruction of the condyles, malposition of the dental articulation and a retardation in the growth of the zygomatic arch.
3. The animal which sustained unilateral condylectomy of the mandible demonstrated a fibrous hinge-like articulation, an open bite and an underdeveloped zygomatic arch.

4. Measurements of the operated mandibles did not differ significantly from that of the control.

On the basis of the preceeding data, the following conclusions were made:

1. All intracapsular subcondylar fractures of the mandible heal with or without reduction or fixation, but demonstrate a medio-lateral widening at the site of fracture.
2. Growth of the mandible persists in these animals.
3. Following condylectomy reconstruction of an articular surface may or may not result, but appositional growth of the body and ramus of the mandible does persist.
4. A condylectomized animal demonstrates a loss of inter-incisal relation.

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APPENDIX

A. TABLES

TABLE 1

PREOPERATIVE OBSERVATIONS

Monkey No.	Sex	Wt. in lbs.	Dentition	Midline of Incisors	Incisal relationship	Hand length in mm.	Estimated age in mos.	Surgery	Post-operative period in months	Crown Rump length in mm.
1	Male	3.7	Deciduous	Normal	Normal	70	18	Bilateral Condylar Fracture and Displacement	12	325
2	Female	4.0	Deciduous	Normal	Normal	65	20	Bilateral Condylar Fracture Reduction and Fixation	12	335
3	Male	3.5	Deciduous	Normal	Normal	70	20	Right Unilateral Condylectomy	12	355
4	Female	3.5	Deciduous $\overline{6\ 6}$	Normal	Normal	70	20	Left Condylar Fracture Reduction and Fixation	12	325
5	Male	3.2	Deciduous	Normal	Normal	70	18	Bilateral Condylectomy	12	342
6	Male	3.0	Deciduous $\overline{6\ 6}$	Normal	Normal	65	19	Right Unilateral Condylar Fracture and Displacement	10	324
7	Male	2.8	Deciduous	Normal	Normal	68	18	Control	10	310

TABLE 2

POST MORTEM MEASUREMENTS (MM.)

Monkey No. and Surgery	P.O. Period in Months	Mandibular Body Length		Mandibular Body Height		Ramus Width		Coronoid Process Height	
		Right	Left	Right	Left	Right	Left	Right	Left
1 Bilateral Condylar Fracture and Displacement	12	58	58.3	18.0	17.8	22.0	21.9	36.0	35.5
2 Bilateral Condylar Fracture Reduction and Fixation	12	56	55.6	16	15.3	21	20.5	35.0	35.2
3 Right Unilateral Condylectomy	12	56.5	58.0	14.6	17.0	18.5	19.8	29.0	31.6
4 Left Condylar Fracture Reduction and Fixation	12	57	56.2	15.1	15.3	19.0	18.7	30.0	29.9
5 Bilateral Condylectomy	12	56	56.5	15.0	15.2	19.0	19.3	30.0	29.6
6 Right Unilateral Condylar Fracture and Displacement	10	54.0	54.6	14.3	14.5	19.1	18.9	30.1	30.3
7 Control	10	58.0	58.2	15.0	15.2	20.0	19.8	33.1	33.4

TABLE 3

POSTOPERATIVE FINDINGS IN MONKEY NO. 1
BILATERAL CONDYLOID FRACTURE AND DISPLACEMENT

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	3.7 3 3/4	Deciduous	70	325	Normal	None
2 Months	4.2	Deciduous $\overline{6\ \ 6}$	74	343	Normal	None
4 Months	5.0	Deciduous $\overline{6\ \ 6}$	78	367	Normal	None
6 Months	5.7 5 3/4	Deciduous $\overline{6\ \ 6}$	83	388	Normal	None
8 Months	5.7	Deciduous $\overline{6\ \ 6}$	94	399	Normal	None
10 Months	6.0	Deciduous $\overline{6\ \ 6}$	104	415	Normal	None
12 Months	6.2 6 1/16	Deciduous $\overline{6\ \ 6}$	114	431	Normal	None

TABLE 4

POSTOPERATIVE FINDINGS IN MONKEY NO. 2
BILATERAL CONDYLOID FRACTURE REDUCTION AND FIXATION

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	4.0	Deciduous	65	335	Normal	None
2 Months	3.5	Deciduous $\overline{6\ \ 6}$	68	340	Normal	None
4 Months	3.6	Deciduous $\overline{6\ \ 6}$	74	348	Normal	None
6 Months	3.8	Deciduous $\overline{6\ \ 6}$	80	360	Normal	None
8 Months	4.2	Deciduous $\overline{6\ \ 6}$	87	383	Normal	None
10 Months	4.8	Deciduous $\overline{6\ \ 6}$	94	401	Normal	None
12 Months	5.4 5 3/16	Deciduous $\overline{6\ \ 6}$	108	430	Normal	None

TABLE 5

POSTOPERATIVE FINDINGS IN MONKEY NO. 3
UNILATERAL CONDYLECTOMY, RIGHT CONDYLE

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	3.5	Deciduous	70	355	Normal	None
2 Months	3.5	Deciduous $\overline{6\ \ 6}$	74	369	Normal	.5
4 Months	3.8	Deciduous $\overline{6\ \ 6}$	78	387	Normal	.75
6 Months	4.2	Deciduous $\overline{6\ \ 6}$	83	400	Normal	.75
8 Months	4.2	Deciduous $\overline{6\ \ 6}$	85	413	Normal	.75
10 Months	4.5	Deciduous $\overline{6\ \ 6}$	88	428	Normal	.75
12 Months	4.8	Deciduous $\overline{6\ \ 6}$	88	438	Normal	.75

TABLE 6

POSTOPERATIVE FINDINGS IN MONKEY NO. 4
LEFT CONDYLOID FRACTURE REDUCTION AND FIXATION

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	3.5	Deciduous $\overline{6\ \ 6}$	70	325	Normal	None
2 Months	3.5	Deciduous $\overline{6\ \ 6}$	72	337	Normal	None
4 Months	3.7	Deciduous $\overline{6\ \ 6}$	76	346	Normal	None
6 Months	4	Deciduous $\overline{6\ \ 6}$	79	358	Normal	None
8 Months	4	Deciduous $\overline{6\ \ 6}$	80	362	Normal	None
10 Months	4.2	Deciduous $\overline{6\ \ 6}$	82	367	Normal	None
12 Months	4.3	Deciduous $\overline{6\ \ 6}$	84	372	Normal	None

TABLE 7

POSTOPERATIVE FINDINGS IN MONKEY NO. 5
BILATERAL CONDYLECTOMY

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	3.2	Deciduous	70	342	Normal	None
2 Months	3.8	Deciduous	74	353	Normal	.5
4 Months	4.6	Deciduous $\frac{6\ 6}{6\ 6}$	79	365	.5	.75
6 Months	6.2	Deciduous $\frac{6\ 6}{6\ 6}$	85	375	1.0	.75
8 Months	6.4	Deciduous $\frac{6\ 6}{6\ 6}$	91	381	1.0	.75
10 Months	6.7	Deciduous $\frac{6\ 6}{6\ 6}$	97	387	1.0	.75
12 Months	6.8	Deciduous $\frac{6\ 6}{6\ 6}$	102	393	1.0	.75

TABLE 8

POSTOPERATIVE FINDINGS IN MONKEY NO. 6
RIGHT UNILATERAL FRACTURE AND DISPLACEMENT

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
At Surgery	3.0	Deciduous $\frac{6\ 6}{6\ 6}$	65	324	Normal	None
2 Months	3.0	Deciduous $\frac{6\ 6}{6\ 6}$	67	332	Normal	None
4 Months	3.8	Deciduous $\frac{6\ 6}{6\ 6}$	71	344	Normal	None
6 Months	4.4	Deciduous $\frac{6\ 6}{6\ 6}$	75	350	Normal	None
8 Months	4.8	Deciduous $\frac{6\ 6}{6\ 6}$	80	362	Normal	None
10 Months	5.2	Deciduous $\frac{6\ 6}{6\ 6}$	84	380	Normal	None

TABLE 9

MONKEY NO. 7
CONTROL

Period Observed	Wt. (lbs.)	Dentition	Hand Length (mm.)	Crown Rump Length (mm.)	Midline	Open Bite
Start of Experiment	2.8	Deciduous	68	310	Normal	None
2 Months	2.8	Deciduous $\frac{6\ \ 6}{6\ \ 6}$	73	314	Normal	None
4 Months	3.0	Deciduous $\frac{6\ \ 6}{6\ \ 6}$	75	327	Normal	None
6 Months	3.3	Deciduous $\frac{6\ \ 6}{6\ \ 6}$	78	328	Normal	None
8 Months	3.5	Deciduous $\frac{6\ \ 6}{6\ \ 6}$	80	335	Normal	None
10 Months	3.8	Deciduous $\frac{6\ \ 6}{6\ \ 6}$	82	343	Normal	None

FIGURE 1. Anterior view of Macaca rhesus monkey skull in animal number 5 (bilateral condylectomy) demonstrating:

A. Loss of incisal relation.

B. Deviation of the mandible to the right.

C. Difference in size of the right and left zygomatic arches.

FIGURE 2. Anterior view of Macaca rhesus monkey skull in animal number 3 (right unilateral condylectomy) demonstrating:

A. Loss of incisal relation.

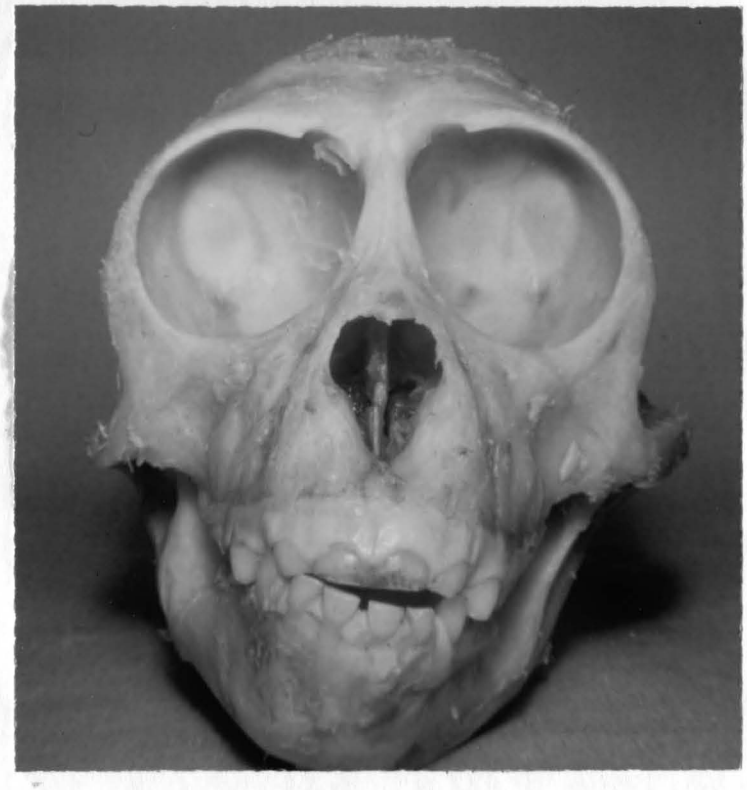


FIGURE 3. Lateral view of Macaca rhesus monkey skull in animal number 3 (unilateral condylectomy) showing the left or unoperated side and demonstrating:

A. The size of the zygomatic arch.

B. The relation of the coronoid process to the zygomatic arch.

FIGURE 4. Lateral view of the Macaca rhesus monkey skull in animal number 3 (unilateral condylectomy) showing the right or operated side and demonstrating:

A. The relation of the coronoid process to the zygomatic arch.

B. The underdeveloped zygomatic arch.

C. The length of the mandibular ramus.

FIGURE 6. Posterior view of the Macaca rhesus monkey skull in animal number 3 (unilateral condylectomy) demonstrating:

A. The relation of the angle of the mandible, both right and left sides, to the base of the skull.

FIGURE 7. Photomicrograph of the frontal section of the right mandibular articulation in animal number 5 (bilateral condylectomy) demonstrating:

A. Eminence of temporal bone.

B. Dense fibrous connective tissue.

C. Cartilagenous island.

D. Muscle tissue.

E. Mandibular articulating eminence.

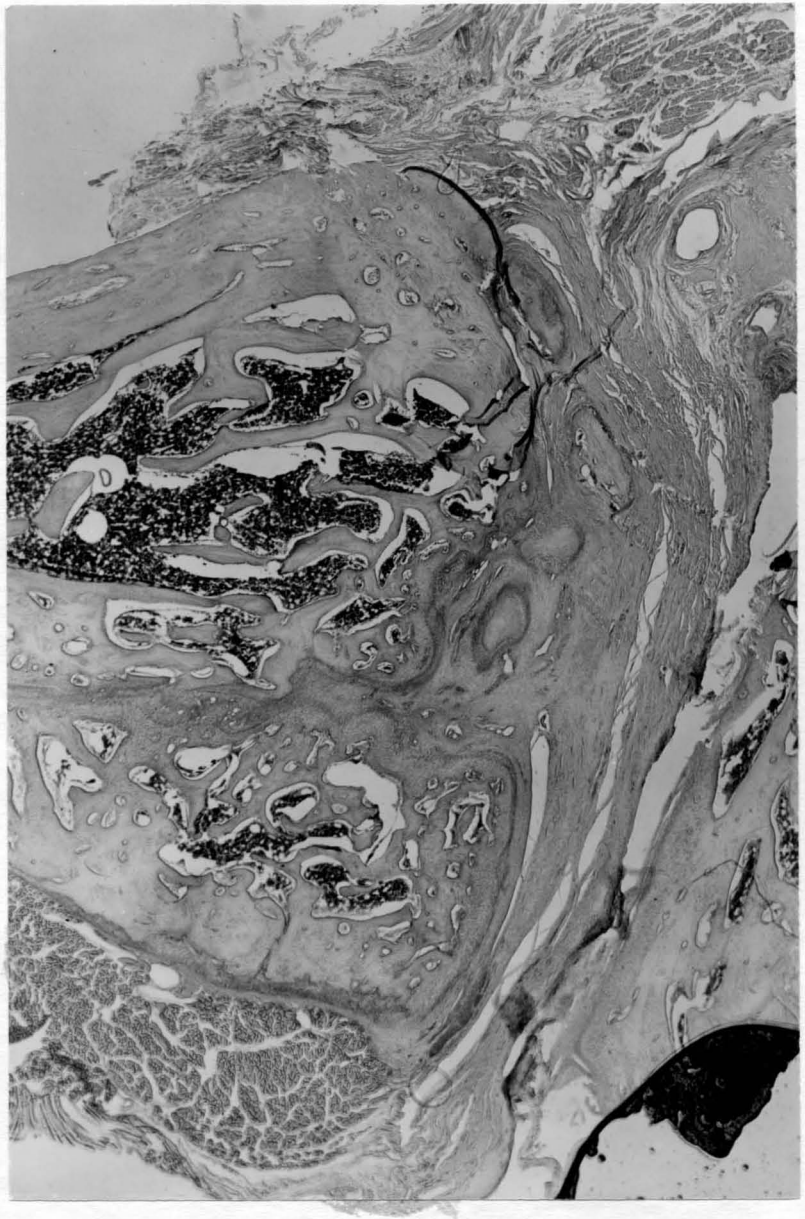


FIGURE 8. Photomicrograph of the frontal section of the left mandibular articulation in animal number 5 (bilateral condylectomy) demonstrating:

A. Eminence of temporal bone.

B. Dense fibrous connective tissue.

C. Muscle tissue.

D. Mandibular articulating eminence.

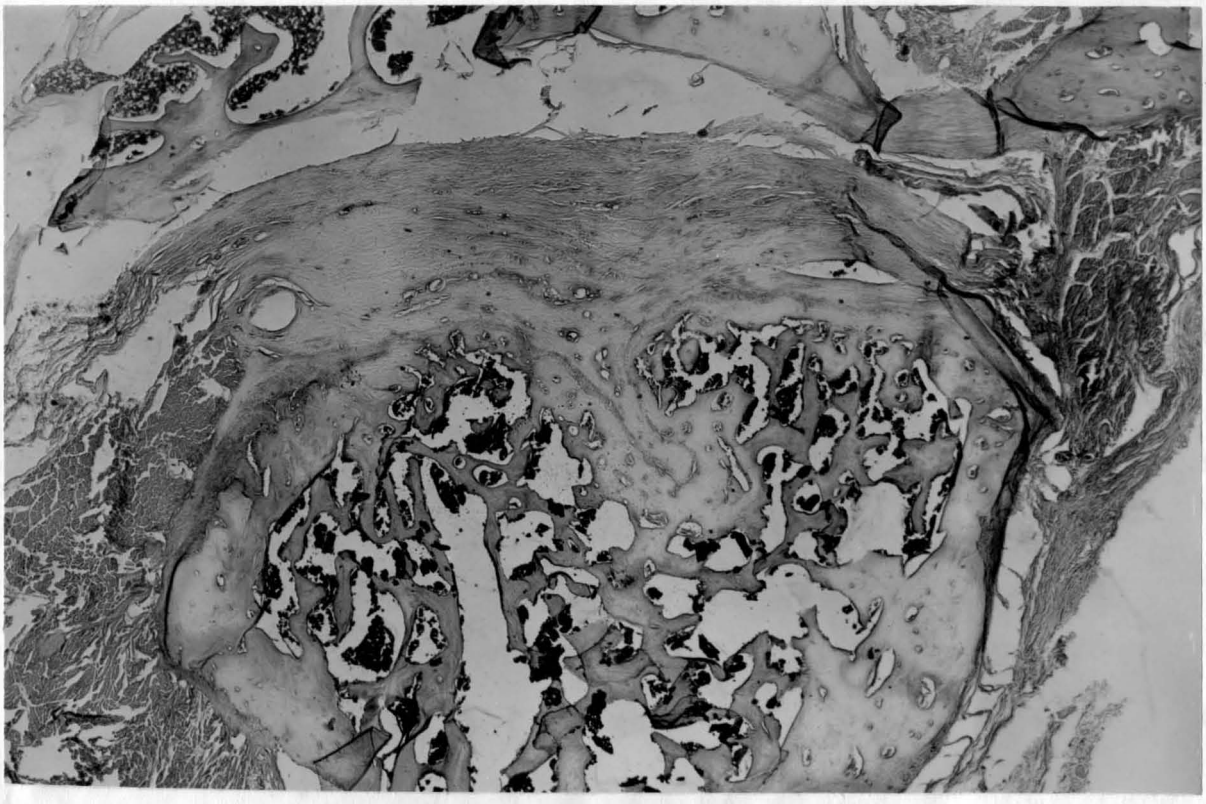
FIGURE 9. Photomicrograph of the frontal section of the right mandibular articulation in animal number 3 (unilateral condylectomy) demonstrating:

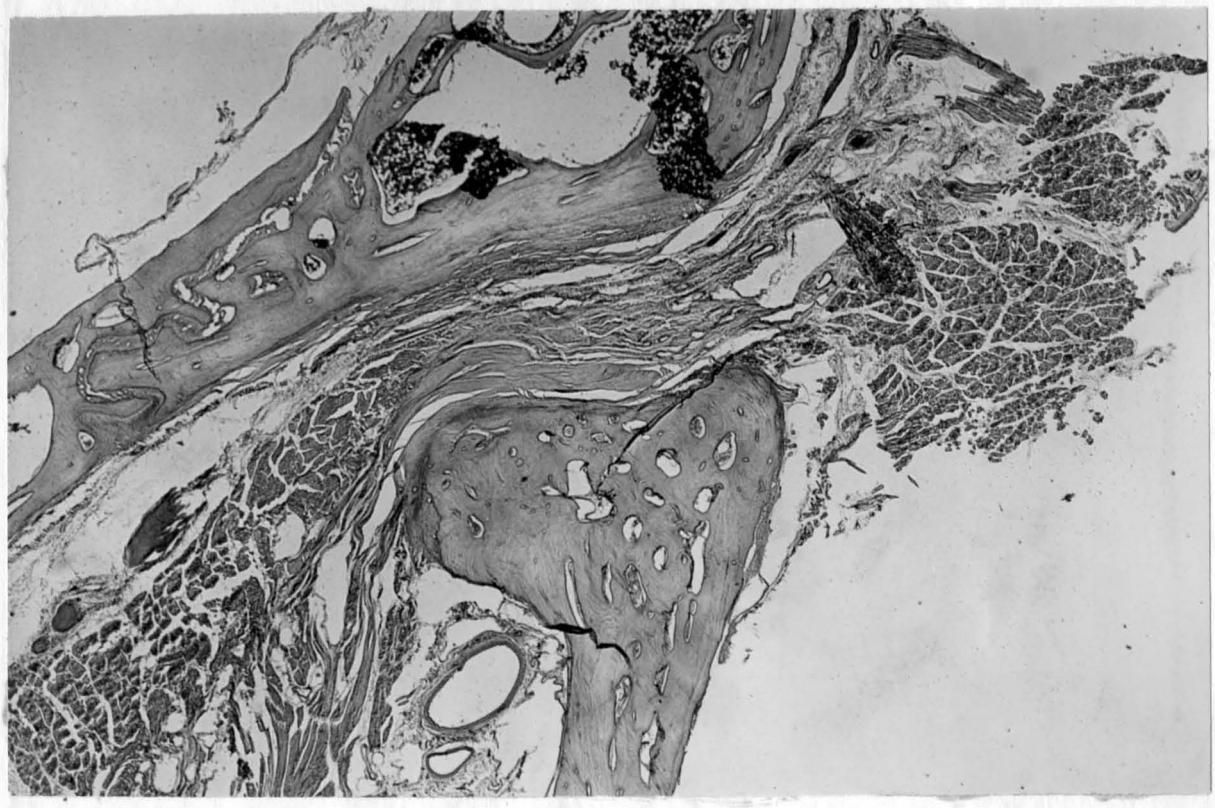
A. Articulating eminence of temporal bone.

B. Dense fibrous connective tissue.

C. Muscle tissue.

D. Amputation site on the mandible.





APPROVAL SHEET

The tehsis submitted by Dr. Jerome E. Schoen has been read and approved by three members of the Graduate School Faculty.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

May 13 1966
Date

Patrick D Suppes
Signature of Advisor